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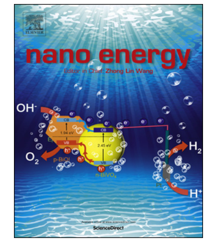

COMMUNICATION

A contact-key triboelectric nanogenerator: Theoretical and experimental study on motion speed influence

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Abstract
Harvesting mechanical energy based on the triboelectric and electrostatic concepts is a very new and extremely fast growing technology. The effect of time in which a typical energy generation cycle occurs is deeply studied here. Three set of contact key with nano-structured triboelectric surfaces, each including a magnetic and fingertip driving mechanisms, were developed and studied. The system is represented by an equivalent circuit, validated by finite element method and the relative mathematical description, and then studied by numerical analysis. It is shown how the relative speed of triboelectric surfaces affects the peak instantaneous and the average power, which is related to the electrostatic phase of energy generation. However, evidences show that the contact/release speed may also influence the charge separation amount, i.e. triboelectric phase of energy generation, which needs to be investigated too.

Introduction

Power in a typical mechanical system is defined as the product of a force on an object and its velocity with which the force is applied. In triboelectric generators, this power is converted into electrical power by the combination of triboelectric and electrostatic effects. Indeed, the surfaces which have contact with each other become triboelectrically charged. The electric energy can be captured as the capacitance created between those charged surfaces varies because of their relative repeated movement. Thus the frequent contact and release between those surfaces determines both triboelectric and electrostatic effects, which finally convert the mechanical energy into the electric energy. Therefore, both force and speed of the contact and release motion

Abbreviations: (ALA), Top Key; K_b, Bottom Key

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should be investigated for characterizing power generation in triboelectric based harvesters. The effect of the applied pressure on triboelectric nanogenerators has previously been investigated [1], confirming that a higher pressure generates a higher power, and this is the theory behind the pressure and tactile sensors concepts [2,3]. However, power generation is also influenced by the stimulation speed which is addressed by investigating how the frequency of the mechanical stimulation affects the generation of energy. Depending on the generator configuration, a frequency increase is the result of a higher number of contact/release operations, which results from different reasons (e.g. pressing with the same speed but with different dwelling time, etc.) but mostly is due to an increase of the speed of relative movements, like in a rotary system [4,5], a 3D composite [6], a vibrating mechanism [7,8], or a contact key [9,10]. Furthermore, in this class of energy harvesters, the two effective phases, triboelectric and electrostatic, can occur together or at two separate times. In other words, the triboelectric phase is observed while the opposite materials are in contact, while the capacitive term is related to the part in which the electrodes move respect to each other. During material sliding in a rotary disc or soft composite functions, these phases may overlap. For example, in a rotary disc, when a top electrode passes through the bottom parallel ones, they may still be rubbed against each other while they experience capacitive variation too. Instead, in the cases of touch keys, vibration systems and similar generators, the triboelectric and electrostatic effects are separated. Here, the stimulation force only affects the contact area and the amount of charge separation in the triboelectric phase, and thus it has no influence on the electrostatic aspects. However, the role of stimulation speed (or frequency) in both phases should be investigated.

The scope of this paper is to deeply study the time in which an external force is applied to a triboelectric nanogenerator that achieves energy harvesting by contact or separation of two different surfaces. This phenomenon is strictly related to the mechanical operation of a triboelectric energy harvester/sensor, and therefore we investigate it here by two different magnetic and not-magnetic based generator types that build up a contact key mechanism. We develop an equivalent circuit model verified by finite element methods, and a mathematical analysis that is simulated by numerical method. In order to validate our model, we experiment the contact key mechanism which employs magnetic force or manual (fingertip) stimulation for the movement of electrically charged surfaces. Micro/nano structures are created on the triboelectric surfaces integrated in the contact key and their durability is evaluated.

Material and methods

Three contact keys are developed as shown in Figure 1. Each key consists of two individual triboelectric nanogenerators. At an initial stage, and if they are not stimulated, the one placed at bottom, called K_b, is closed and the top one, called K_t is open. They are designed and developed to operate in similar conditions and under the same mechanical stimulation, in order to have comparable units. As the scheme of operation shows in Figure 2, when the single contact key is subjected to pressure (e.g. by a fingertip), K_b surfaces are separated until K_t surfaces become mechanically connected. Such position for K_t surfaces actually determines the limit point for the key movement, identifying a constant movable distance for the triboelectric surfaces, which determines the capacitance variation as it

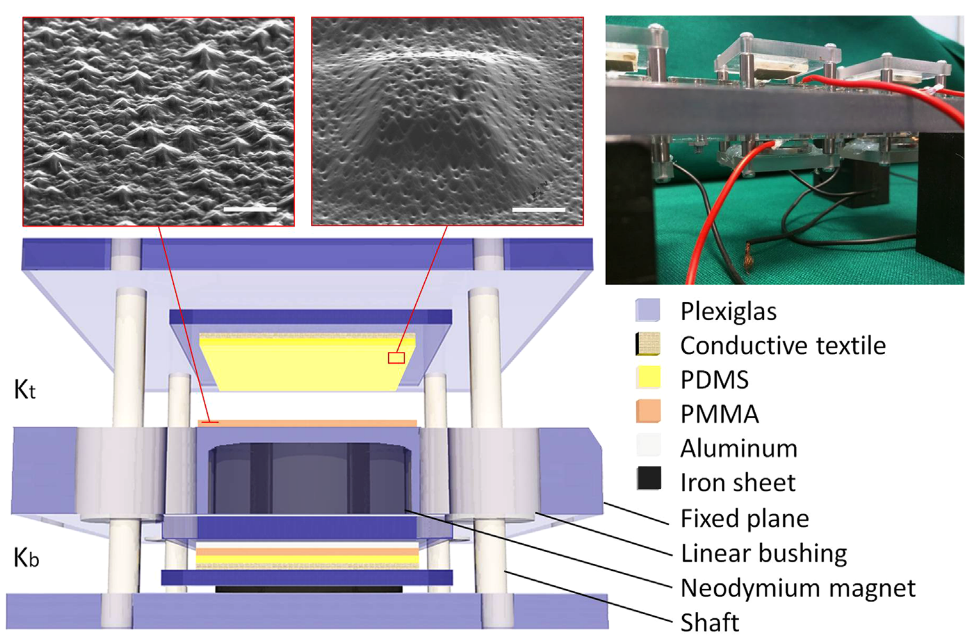

Figure 1 A schematic of one contact key, where the top, K_t, and bottom, K_b triboelectric nanogenerators are indicated. In each of them, the two surfaces that are brought in contact and released (by manual indentation and by magnetic field) are shown by insets at top left, including: left inset: micro/nano-imprinted structures on PMMA, and right inset: hierarchical PDMS patterns; the top right image shows the three built key systems.